Chapter 11

Complex Heterotrophic Eukaryotes (Fungi)

Objectives

Kingdom Fungi. Know the characteristics of fungi. Know the ecological and economical importance of fungi. Understand the similarities and differences between fungi and other kingdoms of eukaryotes. Know some of the symbiotic relationships that involve fungi. Know the components of lichens and understand the roles of each component. Know the characteristics and life cycles, in detail, of zygomycetes, ascomycetes, and basidiomycetes.

Kingdom Fungi

The eukaryotic kingdom Fungi is diverse, versatile, and ecologically and economically important[1]. Fungi occupy diverse habitats (mostly terrestrial) and are important decomposers (saprobes) and participants in symbioses[2]. For example, the ascomycete *Sphacelia* can infect fescue grass (common cattle fodder); the fungus produces alkaloids that are poisonous to herbivores, thus protecting the grass. Fungi are ecologically important and essential; however, they can be an economical nuisance for food produces and distributors. Fungi can grow on living material; thus, causing diseases in plants and animals. Over 5000 species of fungi attack economically valuable crop and garden plants and over 175 species infect humans and domestic animals. For example, *Claviceps purpurea*, an ascomycete-type fungus, infects rye plants and produces alkaloid toxins that can be found in breads made with infected rye grains. These alkaloids, in high doses, cause the disease Ergotism (or St. Anthony's fire) that is accompanied by hallucinations, spasms, and convulsions; however in low doses, these alkaloids are used therapeutically to cause muscle constriction especially in treating high blood pressure.

Fungi are economically important. Certain yeasts produce ethanol and carbon dioxide and therefore are important for baking, brewing, and alcohol production. Fungi provide the distinctive flavors and aromas of some cheeses. Some fungi are delicacies, such as field mushrooms, shiitakes (both of which are grown locally), chanterelles (which are collected locally), truffles, and morels[3]. Importantly, fungi produce many antibiotics, such as penicillin. Cyclopsorin, derived from a soil-inhabiting fungus, suppresses the human immune reactions that cause rejection of organ transplants.

Characteristics of Fungi. Although they share some characteristics with plants and some with animals, fungi have a unique combination of characteristics[4]. All fungi are heterotrophic eukaryotes that are filamentous (filaments termed hyphae and mass of hyphae termed mycelium), unicellular, or coenocytic (rarely). All fungi have chitin-containing cell walls, in contrast to plant cell walls, which contain cellulose (although, a few fungi contain some cellulose in addition to chitin). Most fungi have no motile cells at any stage of their life cycle, in contrast to protists and most animals. All fungi reproduce[5] asexually and, sexual reproduction, when present, is by

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[1] pp. 260-261
[2] pp. 285-291
[3] Fig. 14-3c
[4] pp. 262-265
[5] pp. 264-265

zygotic meiosis; thus, all cells except the zygote are haploid. The most common method of asexual reproduction is by spores, which are usually produced on either sporangia or conidigenous cells. Sexual reproduction in fungi consists of three phases: plasmogamy, karyogamy, and meiosis (to return to the haploid state). Thus, interestingly, as you will see in the laboratory exercises, some fungi have heterokaryotic cells (*i.e.* two or more have genetically different nuclei).

In this lab, we will examine three major groups[6] of fungi, Zygomyceta, Ascomyceta, and Basidiomyceta.

Zygomycetes[7]

A major ecological role of zygomycetes is the formation of mycorrhizae. During sexual reproduction of zygomycetes, they produce a zygospore, or zygosporangium, from which the name is derived. Hyphae of zygomycetes are coenocytic (aseptate) meaning the hyphae lack cross-walls and thus contain many nuclei within the same filament. The following describes the asexual and sexual reproduction of zygomycetes.

Specimen 1: Prepared slide of *Rhizopus* (bread mold)

1. Observe the hyphae of *Rhizopus* at 10x. Notice that the hyphae are aseptate and that the hypha is divided into two parts, the stolon (portion that traverses the surface of the substratum) and the rhizoids (portion that penetrates the substratum).
2. Observe the sporangia (a.k.a. sporangiophore, bodies for asexual reproduction) that produce the asexual spores at the tips of some hyphae. Asexual-spore-containing sporangia enlarge and separate from the rest of the hypha, forming a sac. Then, each nucleus in the sac, along with a bit of cytoplasm, is enveloped by a wall resulting in formation of a spore. When mature, the spores are released and germinate into individual hyphae.
3. During sexual reproduction[8], portions of two hyphae (now called gametangia) that are morphologically similar, but genetically distinct, form protrusions toward each other. The protrusions meet and the membranes fuse, forming a sac that then separates from the hyphae. The nuclei from the two hyphae fuse in pairs, and form a structure, the zygospore (or zygosporangium), containing many diploid nuclei. The zygospore[9] has a thick, protective wall that is resistant to harsh conditions. Under favorable conditions, the nuclei undergo meiosis. The zygospore then "germinates," giving rise to a sporangium with many haploid spores that then germinate to form new hyphae. Observe the fusing gametangia and the zygospores.
4. Draw, at 10x, and label hyphae, the stolon, rhizoids (if visible), sporangia, spores, gametangia, and zygospores.

Ascomycetes[10]

The ascomycetes include many familiar fungi such as truffles, morels, most yeasts, and some molds. During sexual reproduction, ascomycetes form a sac-like structure, the ascus, which bears sexual spores. Hyphae of ascomycetes are septate (cross-walls present); however, they are

[6] Table 14-1
[7] pp. 268-269
[8] Fig. 14-11
[9] Fig. 14-12
[10] pp. 269-272

perforated, allowing organelles (including nuclei) and cytoplasm to pass through. Each hypha is made of many cells, and each cell contains one or two nuclei, depending of the stage of the life cycle. The following describes the asexual and sexual reproduction of ascomycetes.

Asexual reproduction of ascomycetes occurs by formation of uni- or multi-nucleate haploid spores, conidia[11], which form on stalks, conidiophores. Unlike zygomycetes, which produce spores within a sporangium, ascomycetes produce spores externally. Sexual reproduction[12] of ascomycetes involves genetically different mating types (each of which undergo asexual reproduction also) that developed from different spores. When two compatible hyphae come in contact, large multinucleate sac-like gametangia form from each type of hyphae. Plasmogamy of the gametangia occurs producing dikaryotic (each cell has two haploid nuclei) hyphae. The dikaryotic hyphae proliferate by mitosis and organize into a fruiting body termed ascocarp. Dikaryotic cells lining the ascocarp grow into sacs called asci (pl.; ascus, s.)[13]. The two nuclei in each ascus fuse to form a diploid zygote (the only diploid cell in the life cycle) that undergoes meiosis to produce four haploid nuclei within the ascus. Each of the resultant four nuclei undergoes a mitotic division resulting in eight haploid nuclei. Each nucleus becomes surrounded by a thick wall, forming an ascospore (sexual spores vs. conidia, which are asexual spores). When the ascospores are mature, the asci rupture and release the spores, which germinate into haploid, monokaryotic hyphae.

Specimen 2: Prepared slide of a cross-section through the ascocarp of *Peziza*

1. Observe the ascocarp (entire structure) under 4x and 10x.
2. The ascocarp is lined by the asci, which each contain 8 (red) ascospores.
3. Draw, at 10x, and label the ascocarp, hyphae that form the ascocarp main structure, asci, and ascospores.

Specimen 3: Yeast (unicellular ascomycetes), *Saccharomyces cereviseae*

Yeasts[14] are economically invaluable for their use in cooking, brewing, and biotechnology. In addition, yeasts are important model organisms, especially for understanding molecular biology. Most yeasts are ascomycetes. Asexual reproduction of yeasts occurs by mitosis by budding (daughter cells of unequal size) or fission (daughter cells of equal size).

1. Place a drop of yeast culture (grown from commercial baker's yeast in a sucrose solution) on a slide.
2. Dilute with a drop of water
3. Observe at 40x and look for dividing cells.
4. Answer the following question in your lab notebook. Are these yeast undergoing budding or fission? What observation(s) led to that conclusion?

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[11] Fig. 14-15
[12] Fig. 14-14
[13] Fig. 14-16
[14] Fig. 14-31

Basidiomycetes

Basidiomycetes[15] include mushrooms, puffballs, and some pathogenic fungi like the rust and smut fungi.

During sexual reproduction, basidiomycetes bear basidiospores (sexual spores) on the surface of a club-shaped basidium (s.; basidia, pl.) born on a basidiocarp. Hyphae of basidiomycetes have perforated septa; thus, each hypha is made of many cells and each cell contains one or two nuclei (number of nuclei depends on stage of life cycle).

Asexual reproduction in basidiomycetes is a variable character and less prominent than sexual reproduction. During sexual reproduction[16] of basidiomycetes, monokaryotic mycelia of different strains undergo plasmogamy forming a dikaryotic mycelium that forms the basidiocarp (the conspicuous mushroom) through mitosis. Basidia differentiate along the lining of the basidiocarp (*e.g.* the underside of the mushroom cap). The terminal dikaryotic cell undergoes karyogamy, which is immediately followed by meiosis. Each resulting haploid nucleus migrates into the tips of the basidia and is "cut off," forming basidiospores[17].

Specimen 4: Common commercial mushrooms, *Agaricus*

1. Obtain a young basidiocarp of *Agaricus*.
2. Observe the stalk and cap
3. Observe the veil around the cap and the annulus around the stalk. Both the veil and the annulus are derived from a protective covering over very young basidiocarps.
4. Slice the basidiocarp longitudinally.
5. Observe the gills on the underside of the cap. The gills bear the basidia (seen in the next specimen).
6. Draw and label the cap, stalk, gills, veil, and annulus.

Specimen 5: Prepared slide of a cross-section of the basidiocarp cap of *Coprinus*

1. Observe the slide under the 10x objective.
2. Observe the stalk and gills.
3. Observe the layer of basidia lining the gills.
4. Observe the basidiospores (red).
5. Draw, at 10x, and label the cap, stalk, gills, basidia, and basidiospores.

Smuts and Rusts. Smut[18] and rust[19] fungi are plant parasites that do not produce basidiocarps, but do produce basidia and basidiospores. Corn smut[20], *Ustilago maydis*, is a basidiomycete that parasitizes corn. The hyphae penetrate the tissue of the host plant and produce large distended growths in the corn kernels. At maturity, this growth is filled with the dikaryotic spores of the fungus that can overwinter. In the spring, karyogamy occurs in the spores, which then germinate to form a basidium and basidiospores, all within the corn kernel. The monkaryotic basidiospores germinate and the hyphae penetrate corn seedlings. A dikaroytic mycelium forms from

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[15] pp. 272-274
[16] Fig. 14-18
[17] Fig. 14-19
[18] pp. 279-282
[19] pp. 278-279
[20] Fig. 14-30

plasmogamy of the monokaryotic hyphae and spreads through the corn plant causing formation of tumor-like growths.

Rusts have a complex life cycle, which usually involves the obligate, sequential infection of two different plant hosts. For example, the wheat stem rust[21], *Puccinia graminis*, infects barberry plants in the spring, and then form spores, which then infect wheat plants in the summer. An overwintering spore, released from infected wheat plants, then re-infects new barberry plants in the spring. The wheat rust is one of the most destructive of all the species of parasitic fungi. Some control has been achieved by eradicating barberry plants near wheat fields, but total eradication of the secondary host is probably not possible. In recent years, crop scientists have concentrated on developing rust-resistant wheat. This process is continuous because rusts adapt quickly to new varieties through mutation and natural selection.

Lichens

Lichens[22] are symbioses between a fungus (ascomycete or basidiomycete) and a green alga or cyanobacterium. The green alga or cyanobacterium supplies photosynthate to the fungus and obtains from the fungus amino acids, elements for growth, and physical protection from environmental extremes. Although the two components of lichens are clearly recognizable in the microscope, the external morphology of the lichen does not resemble either of its components. Lichens function differently from either the alga or the fungus alone. Lichens have a complex shape and structure that does not resemble either symbiont. Lichens are able to synthesize complex organic compounds, which neither the alga nor the fungus can produce. These compounds are often colored and some have an antibiotic effect.

It is still an open question whether the lichen association constitutes a case of mutually beneficial symbiosis or of a form of parasitism in which the photosynthetic alga is being utilized by the non-photosynthetic fungus. The latter assumption is supported by the following arguments: (1) In many (though not in all) lichens, fungal hyphae penetrate the algal cells and the algal cells may be killed in some lichen associations. (2) The fungus component reproduces sexually, while the reproduction of the alga is inhibited and is strictly asexual.

Lichens live on soil, trees, rocks, *etc*. They survive in extreme environments such as on high alpine rocks, deserts, *etc*. They are the principal components of vegetation in the treeless Arctic tundra (the so-called "reindeer moss" is a lichen) or in the Antarctic dry valleys where they live under the surface of rocks (endolithic forms). Lichens are particularly sensitive to air pollution and their disappearance is a biological indication of increased pollution level.

Review Questions

1. Describe at least one characteristic that fungi share with plants, but not animals, and one that fungi share with animals, but not plants.

2. What characteristics, or combination of characteristics, of fungi are not found in other kingdoms?

3. What are the distinguishing characteristics of zygomycetes, ascomycetes, and basidiomycetes?

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[21] Fig. 14-29
[22] pp. 286-290

4. How does the life cycle exhibited by fungi differ from that exhibited by plants?

5. How are fungi beneficial for farming? How are fungi detrimental for farming?